ABAQUS Modelling and Experimental Tests Comparison for Certain Classes of Composite Isolated Joints

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Abstract

Depending on the type of configuration and connector arrangement, beam-to-column end-plate joints can be rigid, semi-rigid, or pinned. Fully restrained joints are required for rigid frames in which it is anticipated that the frame joints will have adequate rigidity to maintain the angles between intersecting parts in the service condition, ensuring full moment transfer. In contrast, partially restrained joints in semi-continuous frames are distinguished by relative rotations between crossing members, allowing the bending force to be transferred only partially. The concept of utilizing partially restricted, unstiffened joints in construction has gained traction since it looks to be more feasible and inexpensive. Bending transfer in partially constrained joints allows semi-continuous frames to withstand actions. Semi-continuous frames can survive actions due to bending transfer in partially restricted joints. At the same time, a certain degree of rotation is permitted, which improves the overall ductility of these structures. Using thinner end plates than those used in practical applications is one of the most effective ways to affect the ductility of end-plate beam-to-column joints. It was confirmed in a previous experimental study that the composite joints, where the thickness of the end plates is equivalent to about 60% of the diameter of the bolt used in composite joints, were taken into account in subsequent tests, and these studies can be confirmed using ABAQUS and Ls-Dyna modelling. All of these concerns are addressed, and recommendations for numerical modelling methodologies are made in order to ultimately analyse the reaction of the symmetric extended end plate joints with 8-bolts under hogging and sagging bending moments.

Keywords: Joint; Robustness; Finite elements; ABAQUS; LS-DYNA

1 Introduction

The bonding interaction between the concrete and steel elements composing the insulated joint makes nonlinear analysis of composite structures up to the point of failure somewhat difficult due to the complexity of the physical processes that precede the structural failure process under increasing procedures. The reason is a combination of different shear bolt behaviours in steel beams, concrete, and steel columns; the presence of any lateral metal surface; stress redistribution between concrete and rebar after cracking; slippage between steel sections and reinforced concrete slabs; and a variety of other conceivable local effects. This occurs in a structure made of diverse materials such as steel and concrete, and it is all connected to the distinct and complicated behaviours, the influence of overall ductility, and the behavior of the elements, which produces the collapse stress. This research gives a comprehensive investigation into the modelling of composite beam-to-column symmetric extended end plate connections with eight bolts. The class of joints evaluated is based on their steel equivalents, which the authors tested in previous investigations (Gizejowski & Barcewicz 2008). Because the design of these joints varies so greatly, developing a generic mathematical model for predicting joint reaction is unfeasible. Instead, beam-to-column joint tests were performed to find the connection that describes how the moment is conveyed via the joint components. The optimal joint model for this study contains its practical behavior, which is often a modest number of parameters generated from experimental test data. As a result, a dependable rotational moment response for semi-rigid composite joints is required in order to calibrate the analytical formula for the spring rotational momentary characteristic utilized in engineering practice for analysis and design. In order to correctly replicate the different configurations of tested composite joints, the FE analysis performed herein gives advantage to the ABAQUS and Ls-Dyna codes (Hallquist, 2007, 2008). The composite concrete joints, according to the authors Barcewicz W. (2016), have the same composition and patterning as bare steel spans from an end plate spanning from beam to column. The major distinction is that composite joints consist of a poured concrete slab on a steel surface made of rolled sheets, as well as steel shear wire connectors to produce a composite, continuous action between the reinforced concrete slab, beams, and steel-rolling section. The modelling technique was carried out to advanced standards and correctly mimics the laboratory experiment; in particular, the position of the rebar buried inside the concrete slab and the modelling of the concrete itself differ from earlier studies. An essential topic to address when discussing structural robustness and design requirements for circumstances of extraordinary action is a structure's capacity to redistribute pressures internally and so limit the progression of damage. The development of so-called alternate loading routes is primarily accomplished by joint ductility, that is, by ensuring that the joints have adequate rotational capacity.

A structure's resilience is typically examined in analysis by analysing the potential removal of the main structural element(s) and determining if local impact can be absorbed by the decaying structural system. This necessitates research into joint responses to flaccid flexion with axial ligation. In an earlier study of isolated joints (flush and asymmetric extended end-plate), it was discovered that we needed to test the symmetric extended end-plate joint to be more resistant in the presence of positive and negative bending moments, as well as when the joints were subjected to member collapse (column loss scenario). Current advanced modelling approaches are then applied to joints as part of a complicated procedure that arises in the case of progressive collapse and is confirmed through comparisons with experimental test findings. Through energy-based static and nonlinear dynamic studies, the contribution seeks to expand knowledge in the relevant field of study and provide the groundwork for a global evaluation of structural susceptibility to disproportionate collapse. All of the specifics of modelling and simulation of the structural components involved in joint fitting, as well as the method of analysis employed in the software in this research, are the same as those used in earlier finite element analyses (Saleh, 2013). The flanges, web, and stiffener, for example, are 8-node, doubly curved thin shell elements, whereas the concrete deck slab plates of the steel girder are represented by thick shell components. The ABAQUS code's "rebar" layer option was used to represent reinforcement. To account for the geometric and materially nonlinear behavior of continuous steel composite structures, a 3D FE model was developed.

2 Symmetrical Model Development

The finite element model under consideration in this work is an extension of one presented by (Saleh, 2015). The previously utilized finite element joint model Saleh (2020) is transformed into a new model with the following precise requirements: The concrete slab reinforcement is represented by truss components and is situated in the same location as in the tested specimens. The finite element model utilized in this work is an extension of the model used to represent isolated extended end plate joints with 4-6 bolts Saleh (2022), and it has also been employed in earlier investigations of a basic package of isolated joints. The reinforced concrete slab of the composite joint is modelled using various layers of brick finite elements structured so that the slab mesh nodes of certain layers correspond with the top of the shear studs and are in line with the reinforcement. This allows you to simulate the real stud length as well, the matching end nodes of the connected shell components of the beam flange and brick elements of a slab of reinforced concrete. There are two types of numerical analysis considered: static general and explicit dynamic. The influence of finite element mesh size, type, and time step is carefully determined. In the case of steel specimens, both methodologies produce equivalent findings; however, numerical time-explicit analysis is less precise in reproducing the experimental behavior of composite steel-concrete frame specimens. The concrete slab reinforcement is represented by truss components and is situated in the same location as in the tested specimens. The composite reinforced concrete slab is represented by multiple layers of brick-based finite elements organized so that the slab mesh nodes of certain layers correspond with the tops of shear studs and are in line with the reinforcement. This enables the modelling of the actual stud length as well as the matching end nodes of the linked shell components of the beam flange and brick elements of a reinforced concrete slab. The profiled sheeting effect is featured, and the concrete ribs are represented by brick finite elements in the shape of cubes and tetrahedrons, with a homogenous 8-nodal solid element C3D8. Sheeting is represented by thin shell pieces. Bolts are modelled using 3D beam elements of type B31 that allow for transverse shear strain. A circular cross-section between the end plate and the shaft flange represents the bolt section profile; a tiny and particular sliding contact interface is utilized.

3 Test Scenarios

These studies were carried out as part of a prior research effort at the Warsaw University of Technology, in which laboratory experiments were devised to explore the behavior of compound joints subjected to severe stresses Barcewicz (2016). As a follower interested in a scientific study on composite connections (steel and concrete) and their design under service and exceptional loads, I have attended this experimental test since its start. The specimens' beam elements were built of IPE 300, while the columns were composed of HEB 200. Steel grade S235JR was used for all steel elements (beams, columns, and end plates). M20 bolt connections of class 10.9 were used, and the Cofraplus 60 composite flooring was used to cast the concrete slab on the dip-profiled sheeting. The sheeting's ribs were positioned in a transverse orientation to the supporting beams. End plate types are utilized in symmetric extended end plate connections with eight bolts. End plates with a diameter of about 60% of the bolt size used in the endplate-to-column-flange connection were utilized, (Barcewicz, 2008).The sheeting and the headed studs (SD 19 by 100 mm) that were friction welded to the top flange of the beam contributed to the composite action. C25/30 was the concrete class (B30) used, and the main slab reinforcing bars were composed of BSt500S steel. All tests were carried out with the static loads rising monotonically until failure. Two independent jacks were used at 1540 mm from the column face to supply the equal weights to each cantilever point. The symmetrical structure was used to control specimen behavior as well as the impact of defects that might lead to column collapse. Figure 1 depicts the experimental test in general, as well as the lobe structure, whereas Figure 2 shows the experiment's modelling and simulation. The test methods and static loads applied to the joint were designed to model the negative and positive moments of a column loss, and the relationship between the quantity of bending moments on the joint, rotation, and deformation was estimated using Eurocodes EN 1-8 component approach.

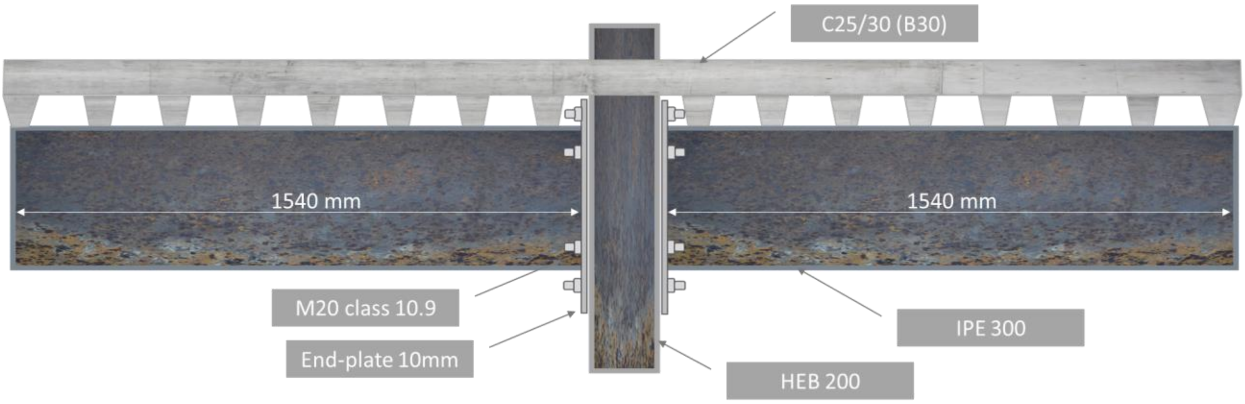

Fig. 1: Composite symmetric extended end plate joint eight Bolts test (Barcewicz, 2016)

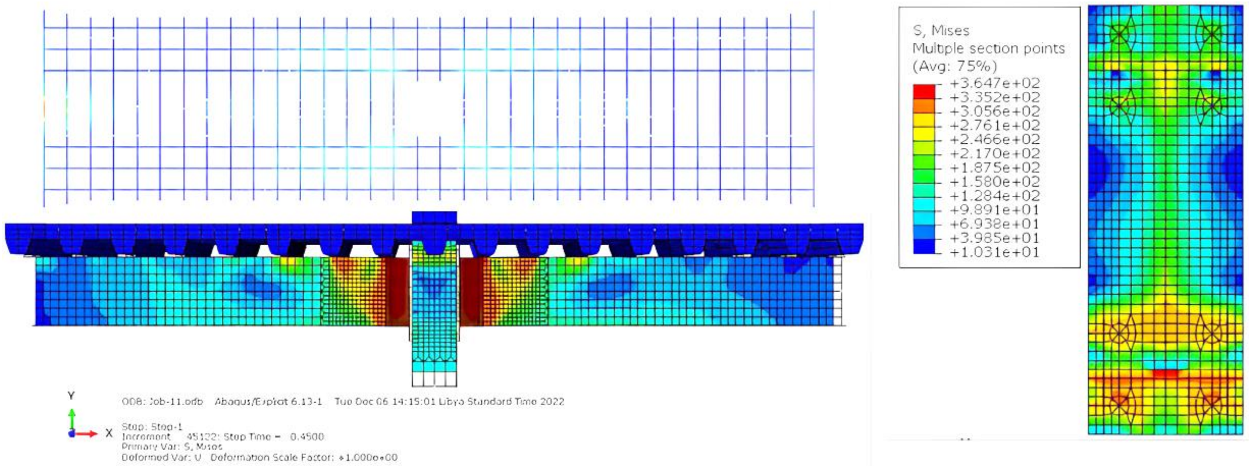

Fig. 2: Displays the stresses in the joint and the overall model using ABAQUS FE modeling

4 FEM Modeling Validation

Since the loading was supplied gradually in the experiment to remove dynamic effects, numerical models reproduce the same time-load characteristic. The chosen FEA modelling technique is validated by comparing the local and global behaviour of the experimentally verified joint and the conformity of force versus displacement relationships is the first indicator of its acceptability. In general, the global behaviour of the investigated composite specimens may be divided into two separate circumstances. Figure 3 illustrates the comparison of joint deformation experimentally and numerically, as well as the percent of agreement between them. For the joints subjected to hogging bending, a significant local deformation takes place at the bottom of the steel plate, both above and below the tensioned beam top flange. The same distortion occurs in the opposite direction in the joint subjected to a sagging bending force. Based on these figures, one might deduce that the symmetrically extended end-plate joints exhibit behaviour that is more ductile. This is owing to the accurate modelling technique utilized, which resulted in consistent and dependable results when compared to the results of the processes experimental test, as well as the appropriate selection of the rebar's diameter and plate thickness. Bolts exhibit no significant elongation in any circumstances, including those subjected to the greatest tensile pressures.

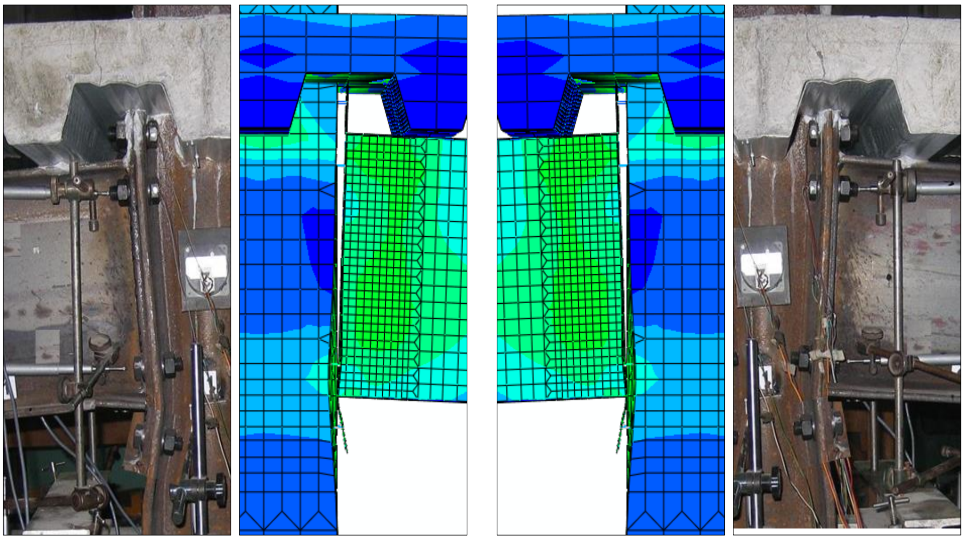

Fig. 3: Joint deformation comparison between experimental testing and FEA modelling

Load-displacement curves and M-ø joint characteristics are provided for the symmetric extended end-plate with 8 bolts specimen. The highest value of the applied load and the ultimate moment derived from the tests and FE models are almost identical (the discrepancy between the ultimate moments does not exceed 9%). The only difference is that the M- ø curve obtains these final values at a different angle of joint rotation, whereas the load-displacement curve obtains them at a different displacement. The highest agreement between the FEM findings and the test data is shown in the elastic range up to about 94% of the final moment, and the impact of the reduction in joint stiffness on the moment value is also clearly visible (see Figure 4 A and B). For the symmetric extended end plate with 8 bolts specimen, load-displacement curves and M- ø joint parameters are shown. The maximum applied load and the ultimate moment determined from the tests and FE models are almost equal (the difference between the ultimate moments is less than 9%). The M- curve obtains these final values at a different perspective of joint rotation, but the load-displacement curve acquires them at a different movement. The best agreement between the FEM results and the test data is demonstrated in the elastic range up to about 94% of the final moment, and the influence of joint stiffness decrease on the moment value is also clearly evident (see Figure 4 A and B).

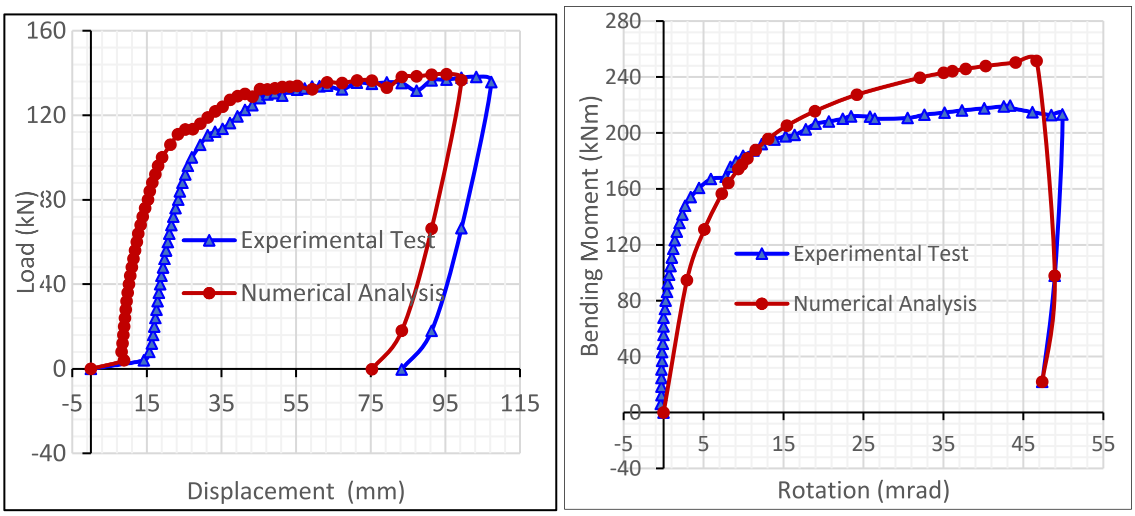

Fig. 4: (A) Force – Displacement relationship (B) Moment – Rotation Relationship of composite joint in experimental testing and FE modeling

5 Conclusion

The strengthening of a concrete slab is reproduced using truss components in the same place as in the tested cases. A composite joint's reinforced concrete slab is modelled using numerous layers of brick finite elements structured so that the slab mesh nodes of certain layers correspond with the tops of shear studs and are in line with the reinforcement. This allows for the modelling of the actual stud length as well as the matching end nodes of the linked shell components of the beam flange and brick elements of the reinforced concrete slab, so this updated numerical model of joint activity has greater accuracy than the previous one and was thus used for the representation of the physical frame evaluated to replicate global behavior for future study. Resistance to progressive collapse scenarios is the most important feature of structural resilience. Both testing and FEA modelling for resilient structural systems should demonstrate that the structure could bear the given load in the case of a worsening static scheme because of local damage modelling. The findings show that structural systems with thin, symmetrically extended end plates are resilient and robust. The numerical model also provides some additional useful information that is difficult to notice during testing, such as the distribution of tension and frictional forces induced by the bolt pre-tension and the moment at the joint, as well as the principal stress flow in the connections. This information is used to build mechanical simulations that comply with the Eurocode component approach to joint design. More emphasis should be placed on discovering creative joint constructional aspects in terms of their ductile behavior, specifically the position of bolts and welding scenarios that minimize the effect of ductility deterioration in the heat-affected zones (HAZs) of beam-to-column joints.

Knowledge of isolated joint stiffness, strength, and ductility in typical conditions and static loads must be increased to incorporate the effect of deformation rate on joint behavior in severe scenarios of local damage.

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